Integrated Design Center / Instrument Design Lab

Ocean Color Experiment Ver. 2 (OCE2) DELTA

~ Concept Presentations~

IDL Systems Engineering

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NASA GODDARD SPACE FLIGHT CENTER

Total Instrument Rack-up

(no contingency included)

OCE2 Ocean Color Experiment Version 2	Total Mass	Total Operating Power (Effective Average)	Total Data Rate
OCE2 Scan Drum Assembly Scanning Telescope Assembly Drum Housing Scan Drum Motor / Encoder Half Angle Mirror Assembly Half Angle Mirror Motor / Encoder Momentum Compensation Assembly Momentum Compensation Motor/Encoder Momentum Compensation Wheel Momentum Compensation Wheel Housing Cradle Assembly Cradle Structure Tilt Mechanism Bracket Tilt Mechanism Motor 1/ Resolver Tilt Mechanism Motor 2/Resolver Calibration Target Assembly Calibration Target Stepper Motor / Resolver Launch Locks (HOP) For Tilt Mechanism- Starsys EH-1540 Aft Optics/Detector Assembly Aft Support Structure Lens/Detector "Six Pack" Assembly Fiber Optics Silicon PIN Photodiode InGaAs PIN Photodiode Preamp, FET switches, FET driver Digitizer Electronics Box Main Electronics Box Mechanism Control Electronics Box Thermal Subsystem	**335.8 Kg** *Details on page 32, 33*	**573 W** **Average** Includes 69W operational heater power *Details on Pages 33*	**Average Data Rate = 41.4Mbps** **Total of 3577Gbits/day** *Details on Page 34*

OCE2 Configurations

OCE2 Configuration	Redundancy Approach	Fore-optics Design	Radiator
Primary BASELINE study: 144 channels	Redundant mechanism control & position knowledge	Singlet	Pocketed
Delta study: 142+32 channels	Single string mechanism control & position knowledge	Doublet	Pocketed

OCE2 Study Parameters

- **Delivery Date: 6/2018**
- **Orbit:**
  - Thermal Analysis assumes 11:00 AM descending crossing for worst case radiator sizing
    - Radiator sizing was primarily driven by the large power dissipation and crossing time has only a secondary impact on the size of the radiator
  - Goal: Noon equatorial crossing time and altitude of ~700 km
    - Different costing times will achieve different SNR performance, as well more coincident science opportunities with spaceflight and possibly ground assets
- **Mission Duration: 3 to 5 years**

OCE2 Study Parameters cont'd

- **Mission Class: C with selective redundancy implemented in the baseline configuration, single string control and knowledge for all mechanisms in the delta configuration**
  - Our reliability consultant A. Brall/300 advised us to implement redundancy for the control and knowledge of all mechanisms operating at 100% duty cycle to meet typical mission-level reliability requirements for Class C missions given the 5 year goal
    - Redundant components are selectable by external command
  - We *typically* strive to achieve an *Instrument* Reliability of 0.85 for a 3 year mission and 0.75 for 5 years
    - Mission level reliability has to account for the S/C and L/V reliability
  - Baseline instrument configuration achieves 87% reliability
    - This yields an 84% mission level reliability assuming a 98% reliable bus and 98% reliable launch vehicle
  - A delta configuration is also shown with single string control and knowledge for all mechanisms, but maintains redundant operational and survival heater control, for an overall reliability of only 71%
    - This yields a mission level reliability of 68% assuming a 98% reliable bus and 98% reliable launch vehicle

Operational Concept

- **Continuous scanning**
  - Raster scan with +/- 51 deg cross track science view
  - Global coverage in two days
  - IFOV 1 km^2 +/- 10%
- **Sunlit portion of orbit, +/- 70 deg lat.**
- **Solar calibration viewing when available during orbit (at terminator crossings) 1x per day**
- **2x orbit inst. tilt pointing (ala SeaWiFS) to +/- 20 deg. for sun glint avoidance (minimization)**
- **monthly S/C slews for Lunar calibration scans**

Driving Design Requirements

Instrument Synthesis & Analysis Laboratory

<table>
<tr><th>Requirement</th><th>Design</th></tr>
<tr><td>

Accommodate continuous scanning telescope

Effective Focal length (mm)	520.36
F/#	2.89
Plate scale	1 km / fiber core (0.8mm)
FOV	1° × 1°
Wavelength range (nm)	350 - 2400
Pupil Diameter (mm)	180

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- 0.620 m telescope assembly
  - Schmidt Plate
  - Primary Mirror
  - Fold Mirror
  - Half Angle Mirror
- Scanning Telescope Mechanism
  - Brushless DC Motor w/ redundant windings and controller
  - 369 rpm
  - Inductosyn absolute rotary resolver w/ redundant readout
  - Rotating Mass 24.11 kg
  - 100% Duty Cycle
- Half Angle Mirror Mechanism
  - Brushless permanent magnet motor w/ redundant windings and controller
  - -184.5 RPM
  - Inductosyn absolute rotary resolver w/ redundant readout
  - Rotating Mass 0.45 kg
  - 100% Duty Cycle
- Momentum Compensation Mechanism
  - Brushless permanent magnet motor w/ redundant windings and controller
  - 1476 RPM
  - Resolver w/ redundant readout
  - Rotating Mass 18.61kg
  - 100% Duty Cycle

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Driving Design Requirements

Requirement	Design

Fiber feed focal plane to optics detector assemblies
• 144 channels
• 800 um core fiber (40um cladding)
• Minimum bend radius 100 mm (4”)
	• Optic / Detector Assembly
	  • Singlet Lens
	  • Photodiode (1 per assembly; 138 Si, 6 InGaAs)
	  • Pre-amp and FET Switches
	  • ~25mmx25mmx150mm
	• “Six-Pack”
	  • 2x3 mechanical module for 6 Optics/Detector Assemblies
	• Aft Optics/Detectors Structural Support
	  • Supports 24 “Six Packs”
	  • Provide structural features for routing/supporting fiber optic bundles

Tilt scanning telescope assembly +/-20 degree (forward/aft scanning) • Additional position to support calibration target observation	• Two stepper motor gear boxes with 12 bit resolvers that operate simultaneously to achieve target tilt position • -20deg, 0 deg (calibration position), +20 deg position • No hardstops • Launch Lock (HOP actuator) cage instrument for launch • Time allowed for 20^{o} motion = 13 seconds (based on SeaWiFS) and the tilt motion is uncompensated

Driving Design Requirements

Instrument Synthesis & Analysis Laboratory

Requirement	Design

Daily Calibration	• Calibration Assembly
	  • 3 position actuator
	  • 2 positions for diffuser plate (solar illuminated)
	  • 1 closed position
	  • Perforated plate at entrance

Driving Assumptions

- **Spacecraft slews to position scanning telescope for monthly lunar calibration**
  - No additional ports included in instrument design to support lunar calibration
- **No onboard data processing beyond digitization and compression (in hardware) and typical data formatting and time-stamping (in software)**
  - Telemetry segmented into
    - Housekeeping
    - Science/Calibration
  - No provision within instrument for special processing of data slated for direct broadcast
    - Direct broadcast feature must consider where and how to implement the functions to distill out the portion of raw science data of interest, as well as to process it for the broadcast recipients
    - In some conversations, the broadcast feature was intended for fisherman that would have limited processing capability to produce useful fishing data from the raw data produced by the instrument
- **Spacecraft discards / ignores science data outside areas of scientific value**
  - Dark side of orbit
  - > 70deg latitude
- **Spacecraft ACS hardware and Instrument mechanism position outputs are sufficient to meet instrument science data geo-location requirements**
  - R. Wesenberg provided a quick calculation of the pointing knowledge needs
    - He estimated that the knowledge needed to be 29arcsec for 1km channels and 5arcsec for the 250m channels (cumulative sum of error sources)
    - The Science Definition Team (SDT) is expected to confirm this assessment

Design Discussions

- **Additional atmospheric channels with 250m resolution have replaced 2 of the original channels**
  - Baseline configuration included 144 total channels
  - We replaced 2 of those with 32 atmospheric channels with Silicon detectors
  - Total of 174 channels increases overall instrument power and mass
  - The delta study will also show a doublet lens assembly, and a single string approach for the control and knowledge of the 100% duty cycle mechanisms
- **Auto adjustment of integration period**
  - Limited to 12 channels only (even in the Delta case, per J. Smith)
  - Implemented through FSW
- **Guidelines for implementing fiber optics documented in Backup charts**

OCE2 Mechanical Layout

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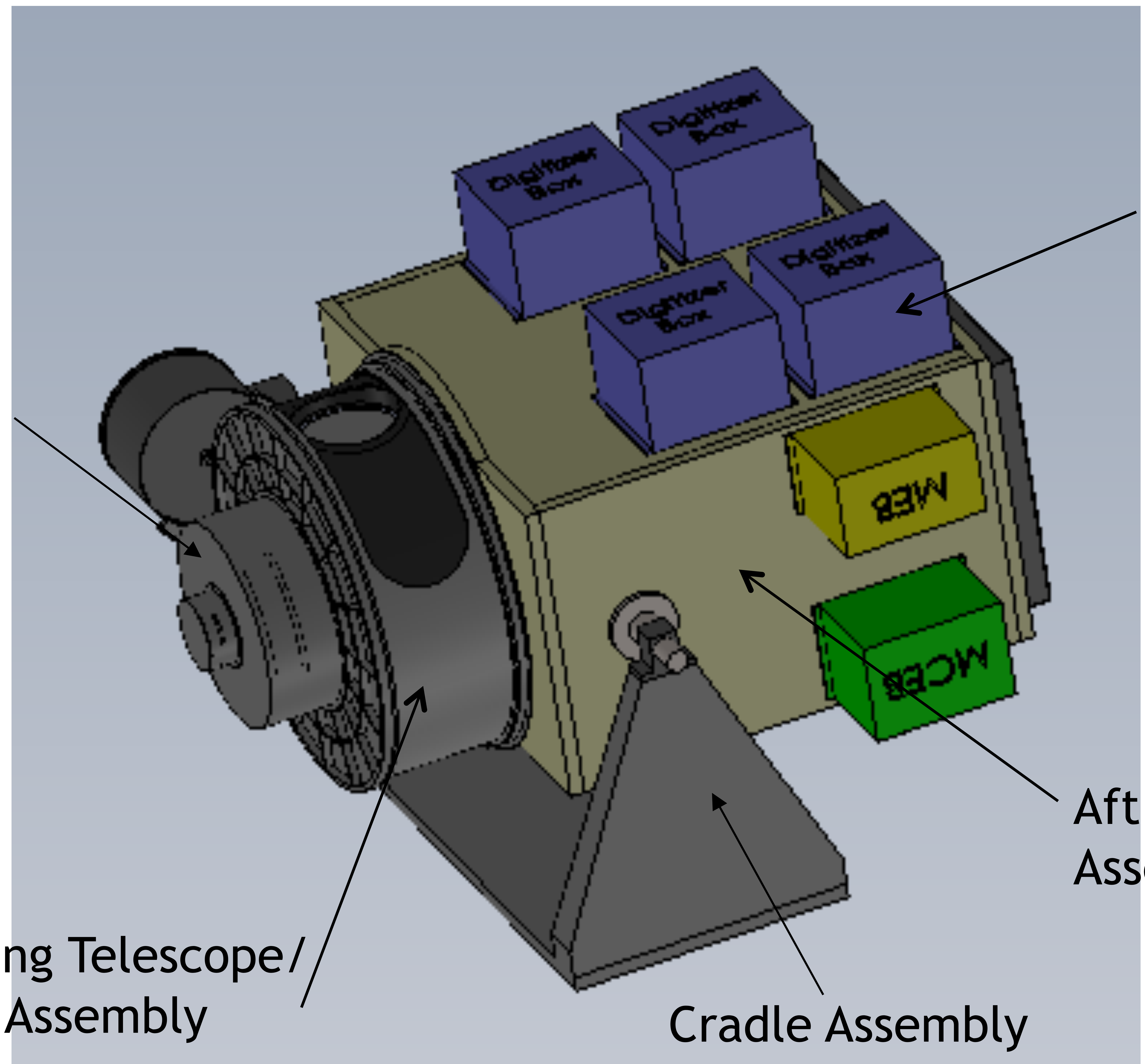
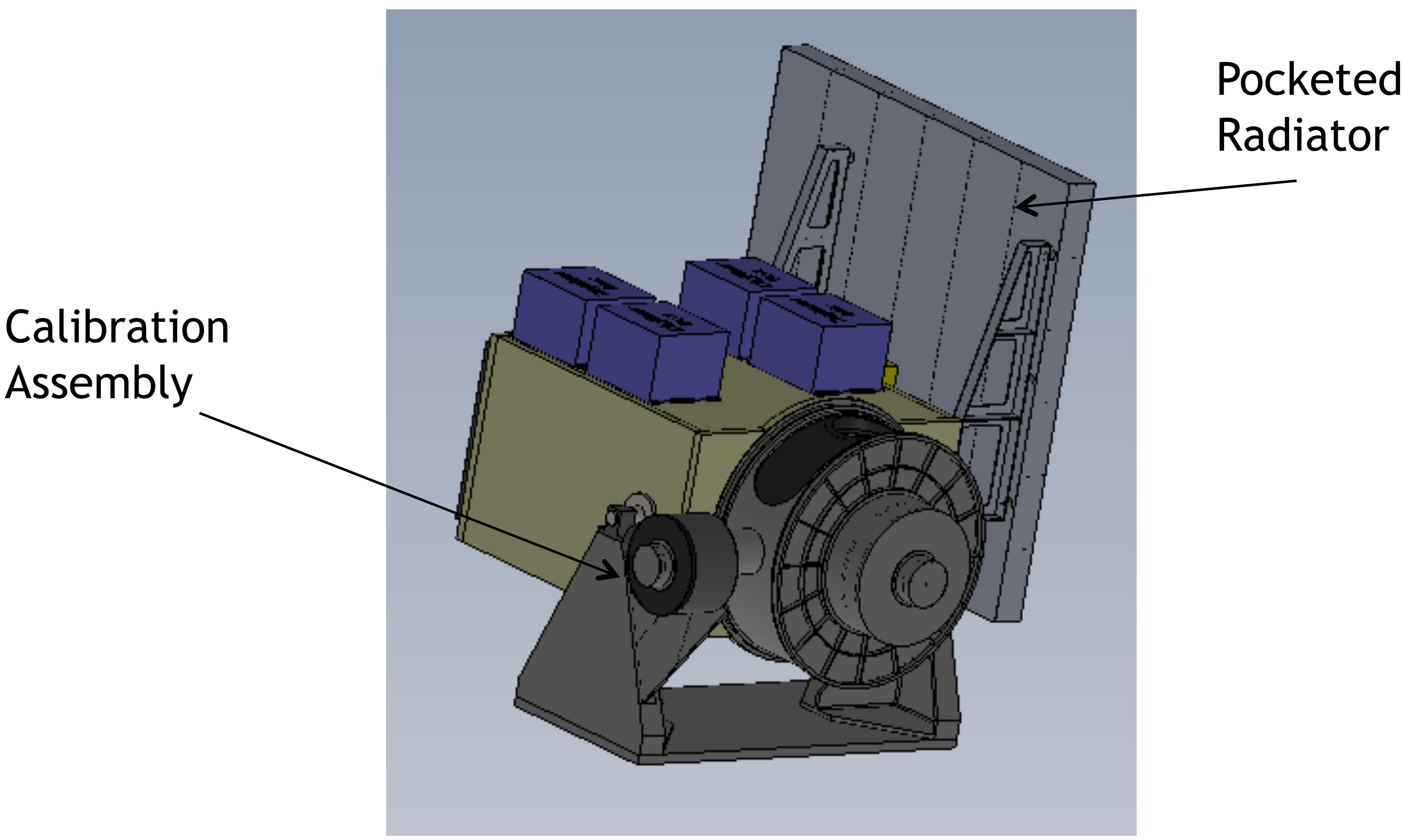
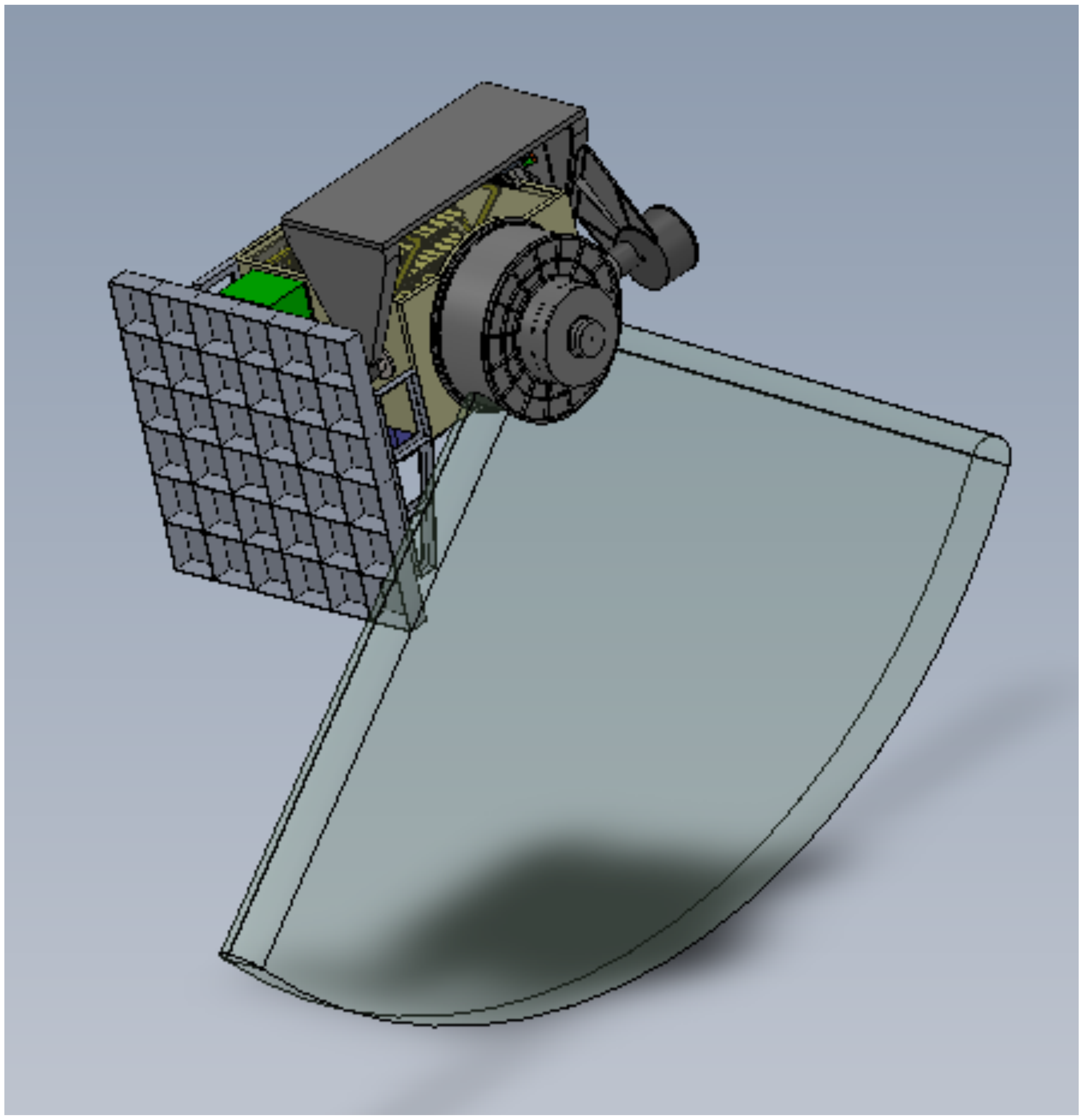


OCE2 Mechanical Layout

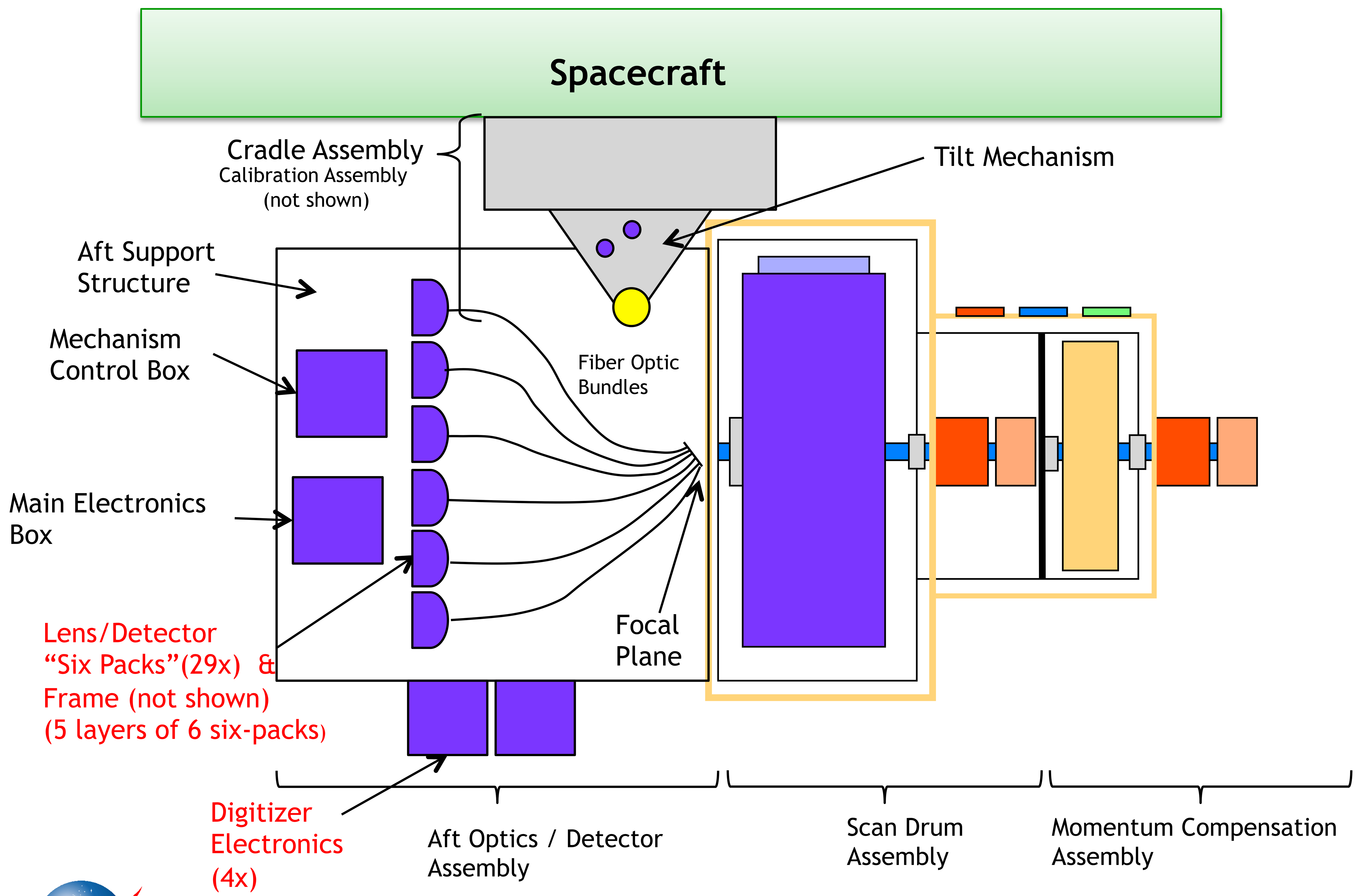


OCE2 Field of View



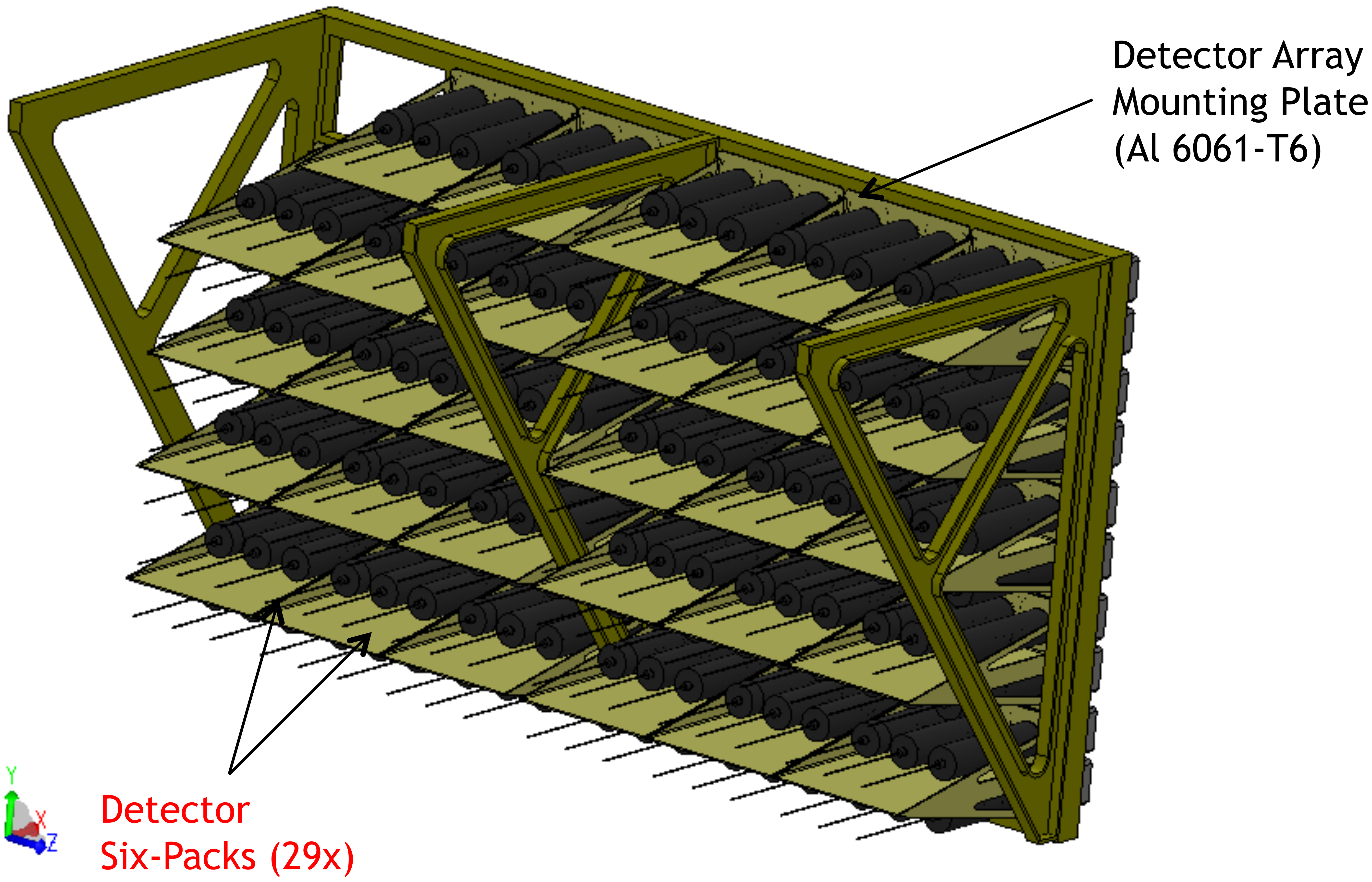
OCE2 Top Level Block Diagram

Instrument Synthesis & Analysis Laboratory

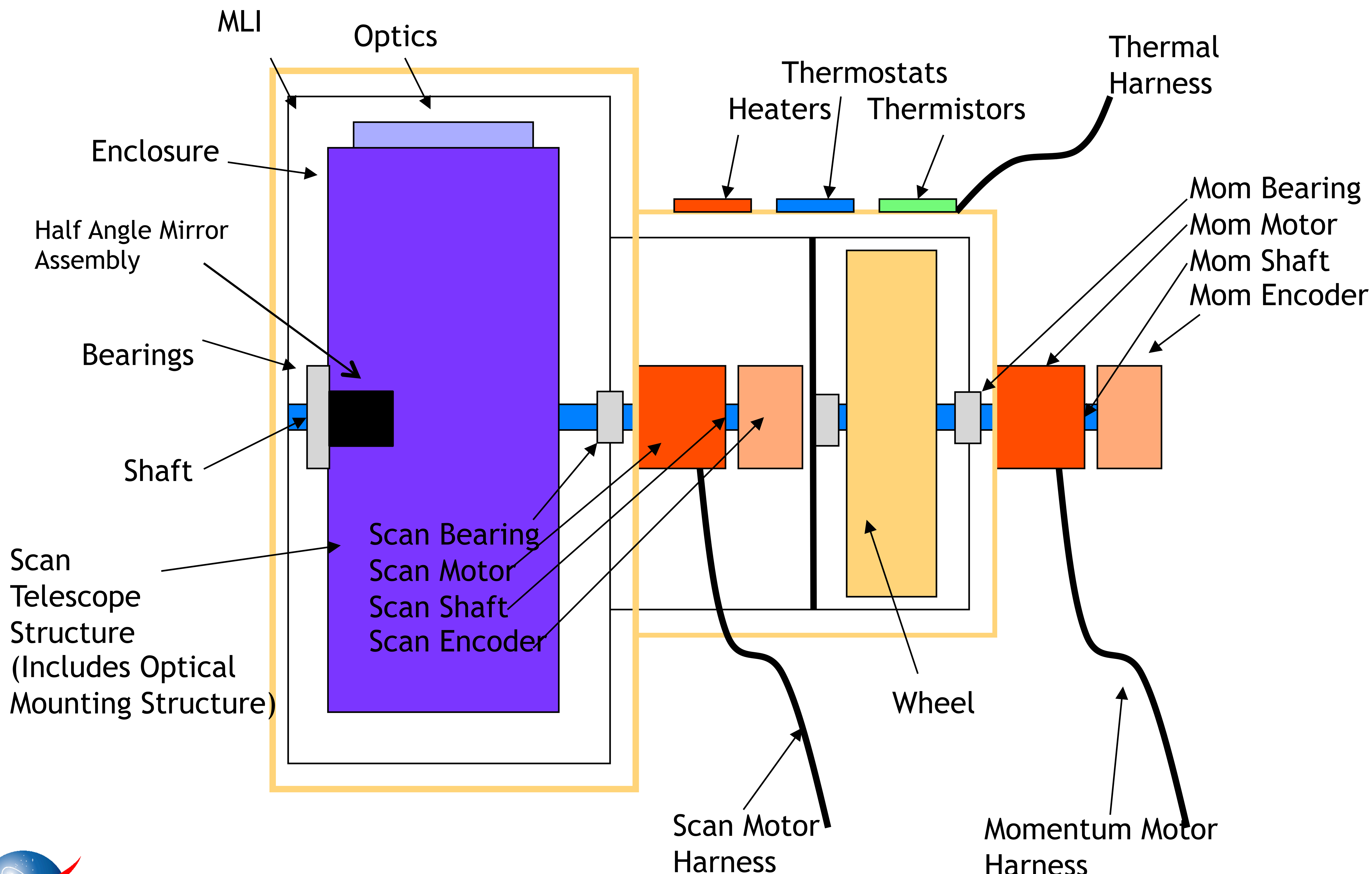


Detector Array Assembly

Instrument Synthesis & Analysis Laboratory

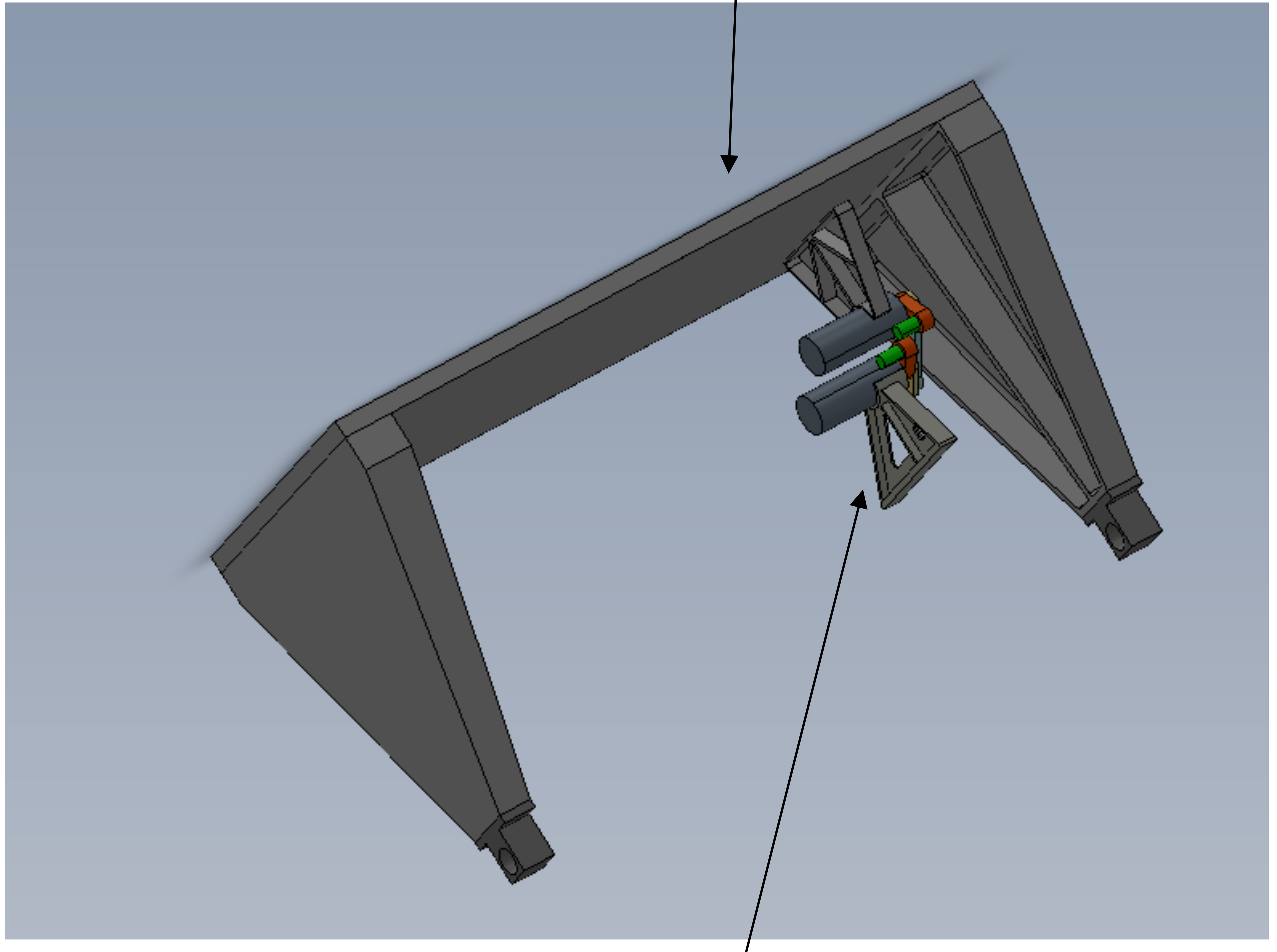


Scan Telescope and Momentum Compensation Notional Block Diagram



Cradle Assembly

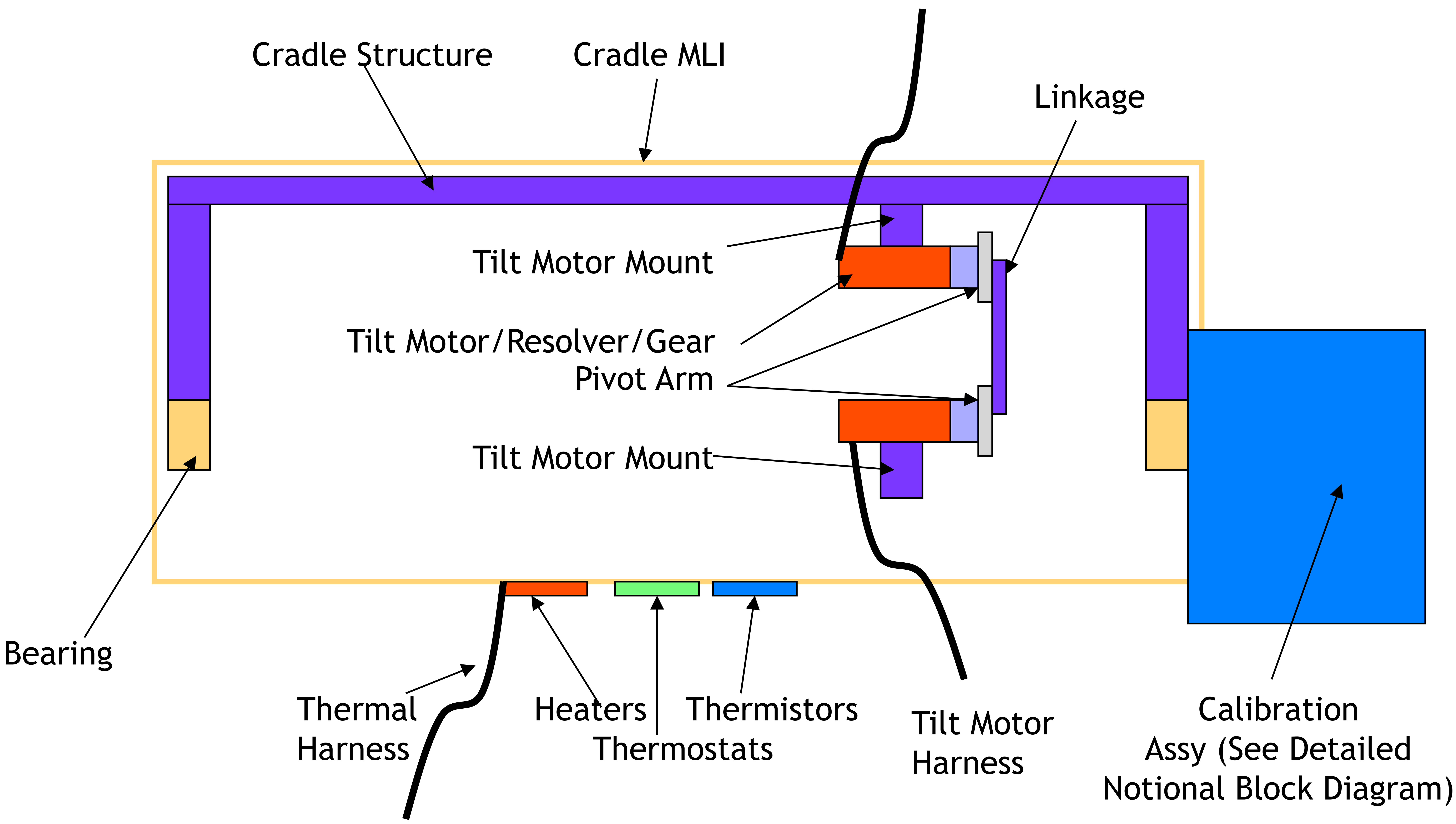
Cradle Structure



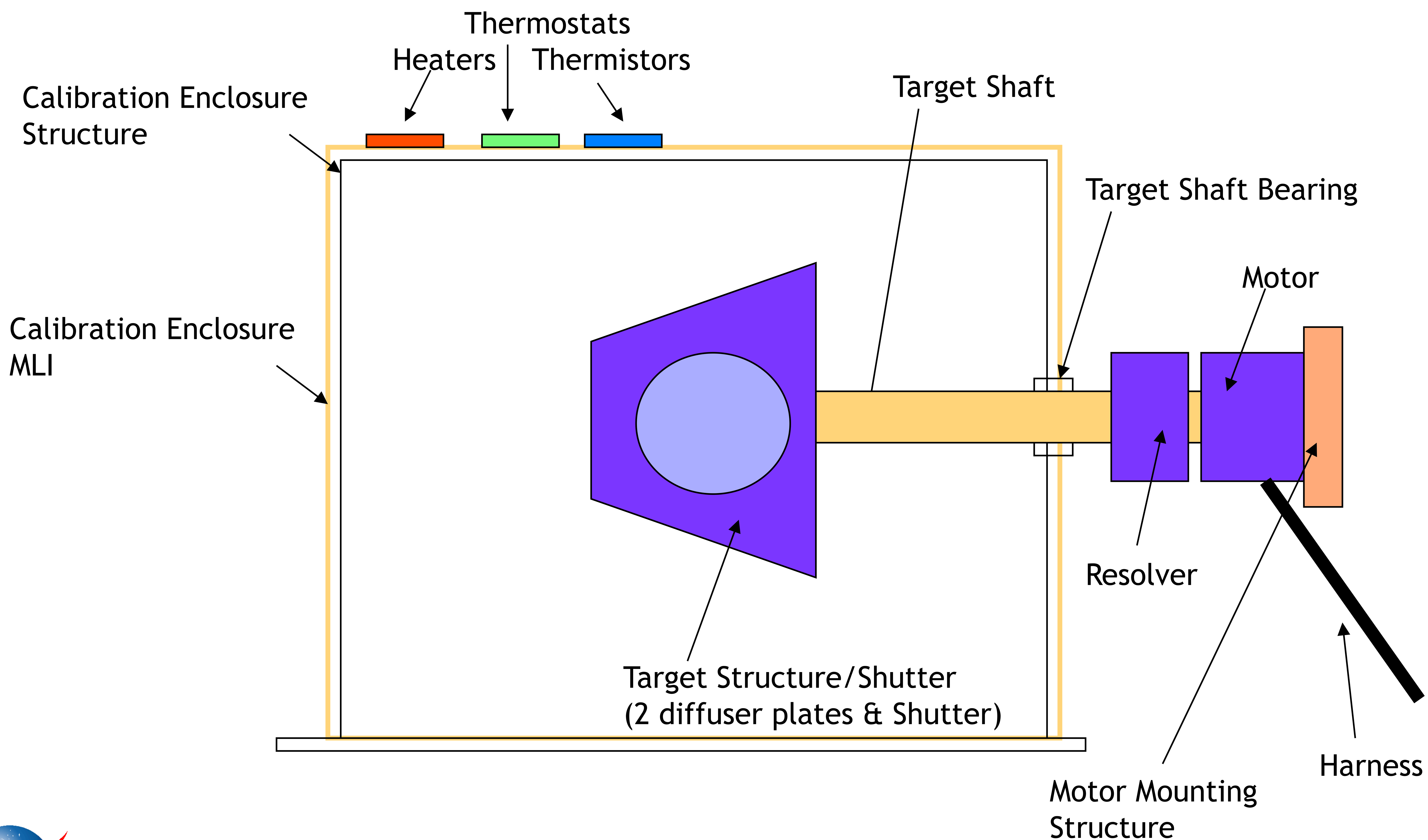
Tilt Mechanism Assembly

Cradle Assembly Notional Block Diagram

Instrument Synthesis & Analysis Laboratory



Calibration Assy Notional Block Diagram



Lens/Detector Assembly "Six-Pack"

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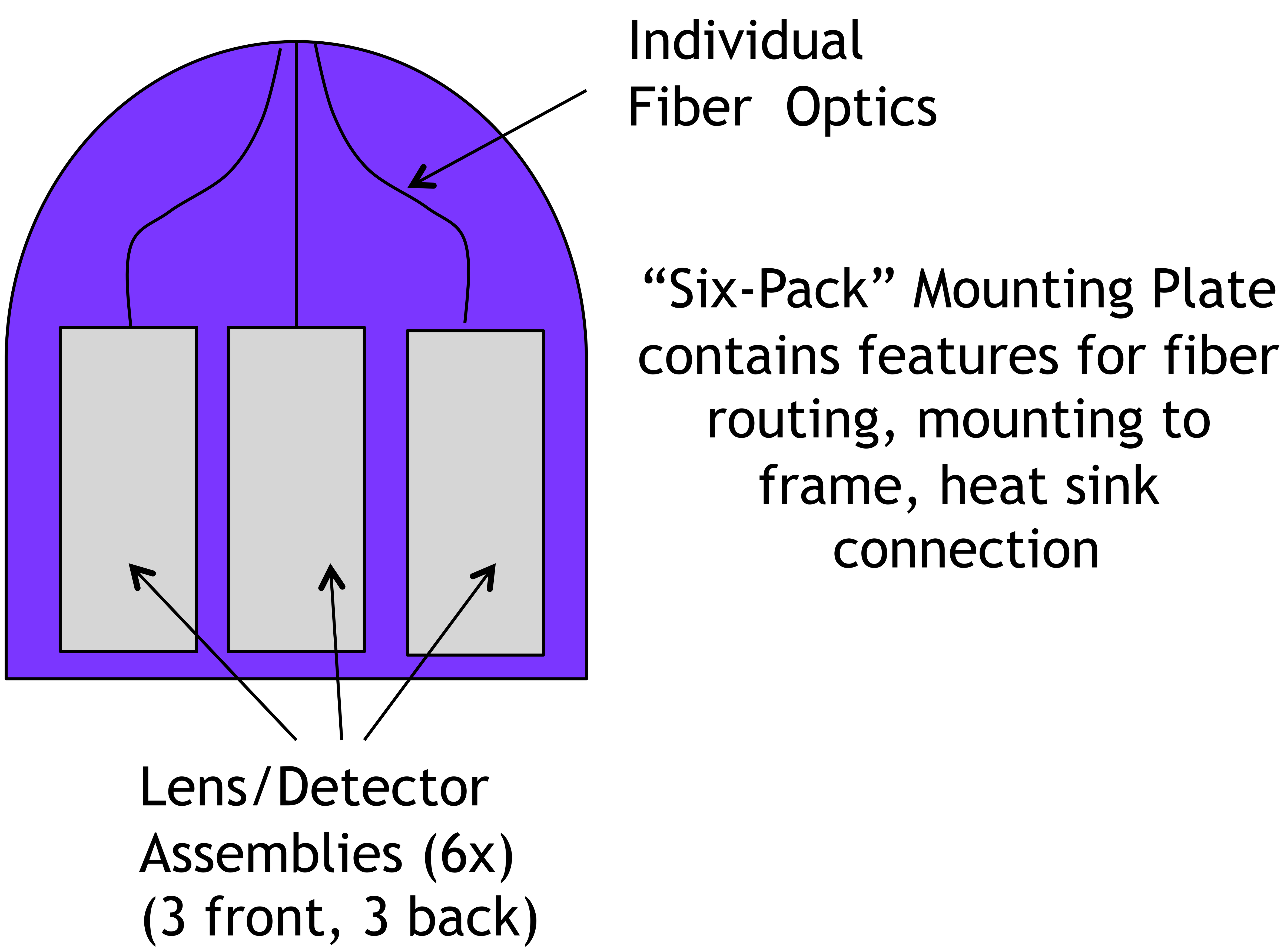
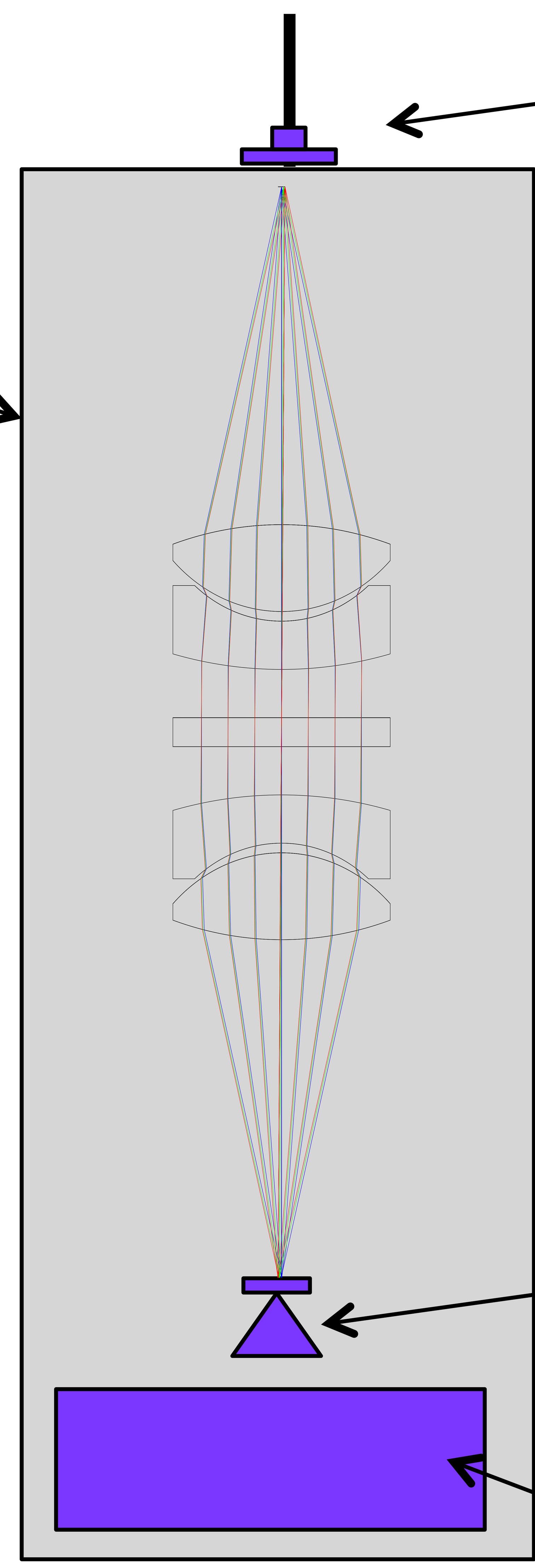


Doublet Lens/Detector Assembly

Lens/Detector Assembly Housing

Materials:
- Al Optics Tube
- Lenses were assumed to be mounted in invar retainers for ease of handling (because of their small size)
- STOP analysis would be required to confirm material choices and mechanical tolerances and alignment sequence



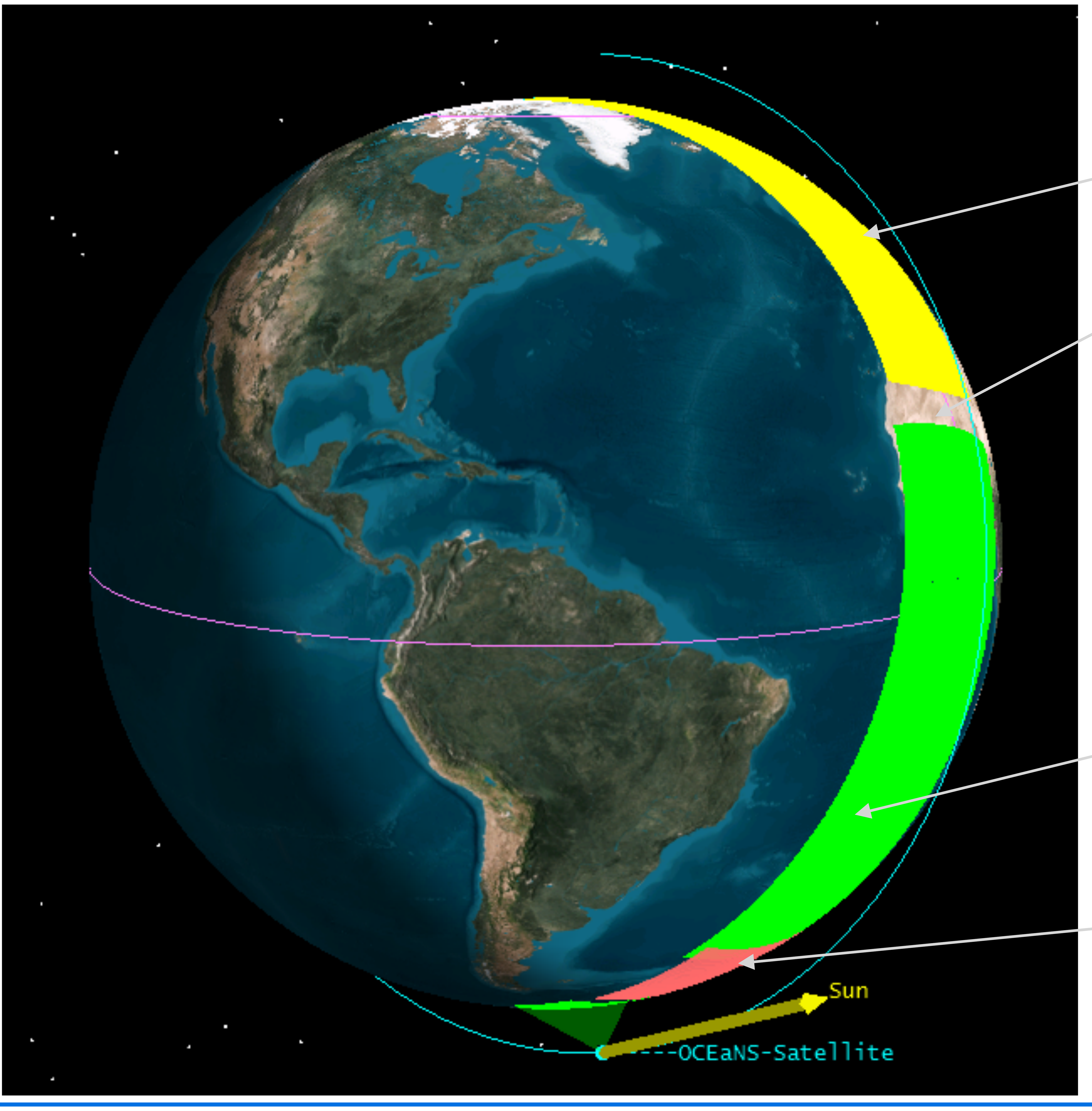
Fiber Optic Connector

Doublet Lenses
- 5 optics (vs. 3 in the singlet design)
- Slightly longer housing
- provide less throughput
- require less (or no) alignment

Detector (Si, or InGaAs Photodiode)

Pre-amp and FET Switches

Forward and Aft Scans Switched at Sun Zenith



Aft Scan

Switch at Sun Zenith

Forward Scan

Cal. Scan

Forward and Aft Scans, One at a Time, Just Past Sun Zenith Switchover

Augmented Table 1

#	User	λ	BW (FWHM)	Spatial Res.	L_{typ}	L_{max}	SNR
		nm	nm	km^2	mW / cm^2 - sr - µm		
1	Oceans	350	15	1 x 1	7.46	35.6	300
2	Oceans	360	15	1 x 1	7.22	37.6	1000
3	Oceans	385	15	1 x 1	6.11	38.1	1000
4	Oceans	412	15	1 x 1	7.86	60.2	1000
5	Oceans	425	15	1 x 1	6.95	58.5	1000
6	Oceans	443	15	1 x 1	7.02	66.4	1000
7	Oceans	460	15	1 x 1	6.83	72.4	1000
8	Oceans	475	15	1 x 1	6.19	72.2	1000
9	Oceans	490	15	1 x 1	5.31	68.6	1000
10	Oceans	510	15	1 x 1	4.58	66.3	1000
11	Oceans	532	15	1 x 1	3.92	65.1	1000
12	Oceans	555	15	1 x 1	3.39	64.3	1000
13	Oceans	583	15	1 x 1	2.81	62.4	1000
14	Oceans	617	15	1 x 1	2.19	58.2	1000
15	Oceans	640	10	1 x 1	1.9	56.4	1000
16	Oceans	655	15	1 x 1	1.67	53.5	1000
17	Oceans	665	10	1 x 1	1.6	53.6	1000
18	Oceans	678	10	4 x 4	1.45	51.9	2000

Ref:

PACE Ocean Measurement Requirements V10-d.docx

&

Measurement_Requirement_OES_Atmo_17Apr12.docx

Augmented Table 1 (Cont'd)

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#	User	λ	BW (FWHM)	Spatial Res.	L_{typ}	L_{max}	SNR
		nm	nm	km^2	mW / cm^2 - sr - µm		
19	Oceans	710	15	1 x 1	1.19	48.9	1000
20	Oceans	748	10	1 x 1	0.93	44.7	600
21	Oceans	765	40	1 x 1	0.83	43	600
22	Oceans	820	15	1 x 1	0.59	39.3	600
23	Oceans	865	40	1 x 1	0.45	33.3	600
24	Oceans	1245	20	1 x 1	0.088	15.8	250
25	Oceans	1640	40	1 x 1	0.029	8.2	180
26	Oceans	2135	50	1 x 1	0.008	2.2	100
27	Atmos	940	15	1 x 1	0.78	21	150
28	Atmos	1378	10	1 x 1	0.35	9.5	100
29	Atmos	2250	50	1 x 1	0.07	2.1	150
30	Atmos	2250		.25 x .25			
31	Atmos	865		1 x 1			
32	Atmos	865		.25 x .25			
33	Atmos	1640		1 x 1			
34	Atmos	1640		.25 x .25			
35	Atmos	2135		1 x 1			
36	Atmos	2135		.25 x .25			
37	Atmos	763		1 x 1			
38	Atmos	763		.25 x .25			

Ref:

PACE Ocean Measurement Requirements V10-d.docx

&

Measurement_Requirement_OES_Atmo_17Apr12.docx

Optical telescope Parameters

Effective Focal length (mm)	520.36
F/#	2.89
Plate scale	1 km / fiber core (0.8mm)
FOV	$1^\circ \times 1^\circ$
Wavelength range (nm)	350 - 2400
Pupil Diameter (mm)	180

Telescope layout

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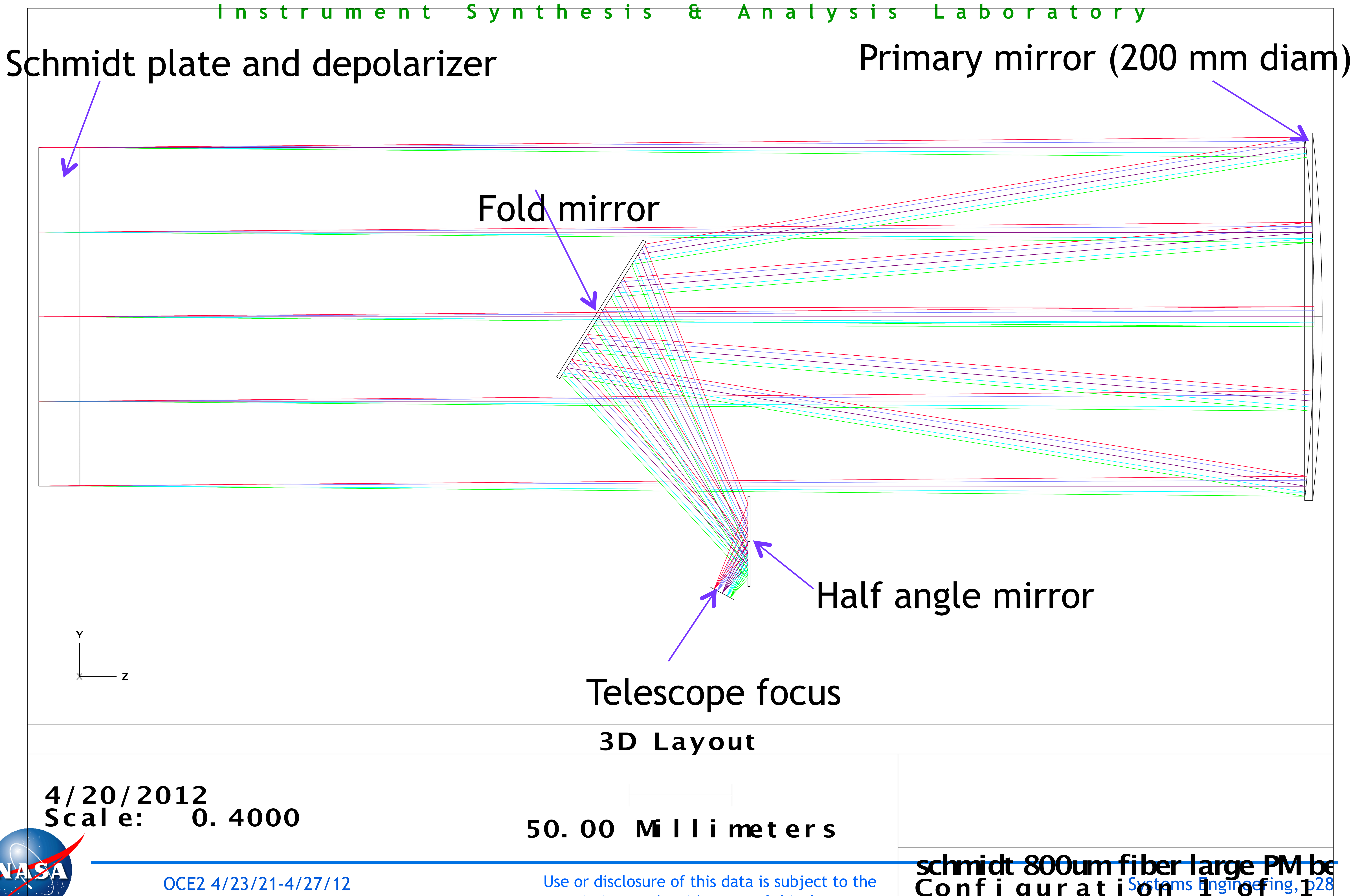
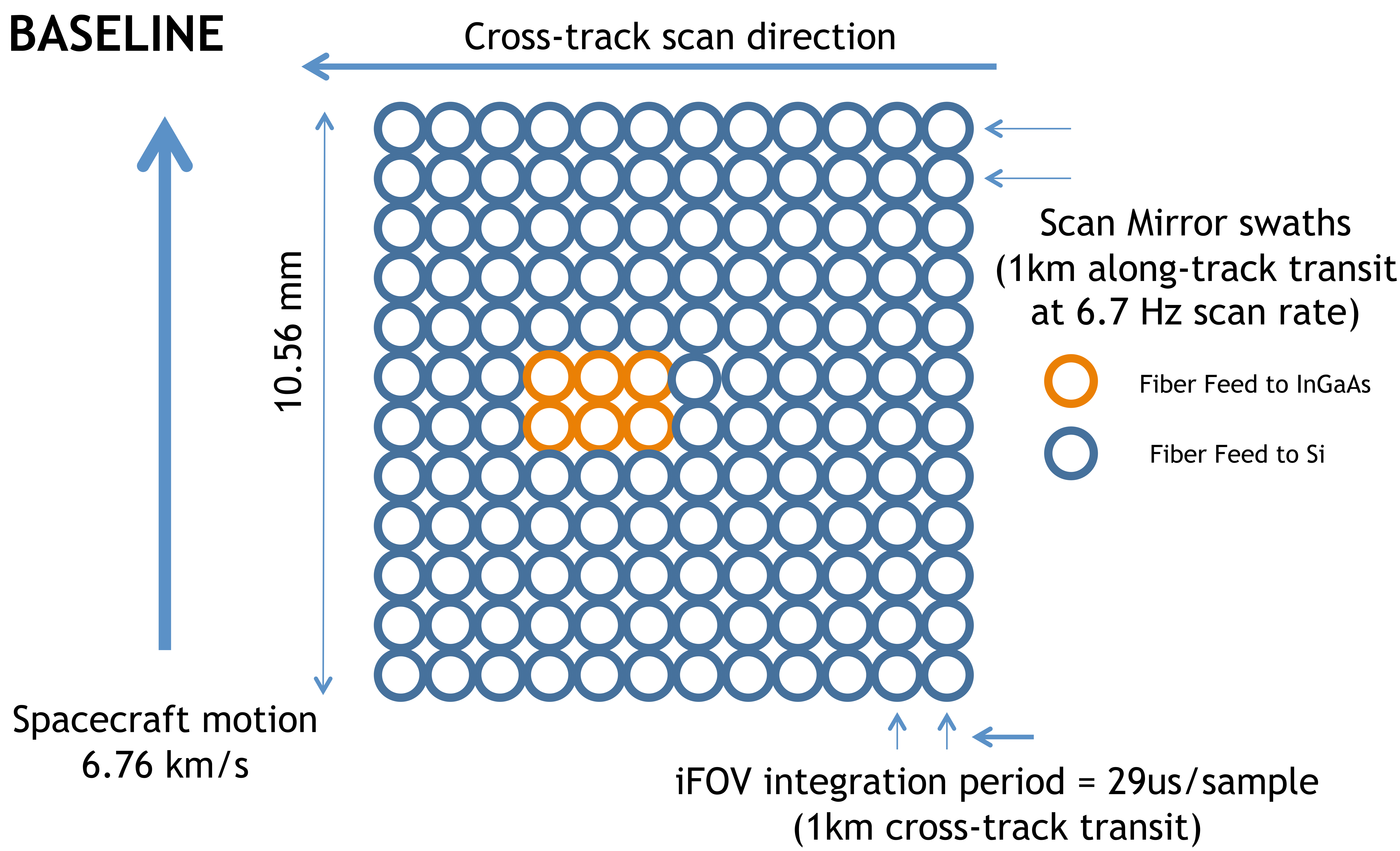


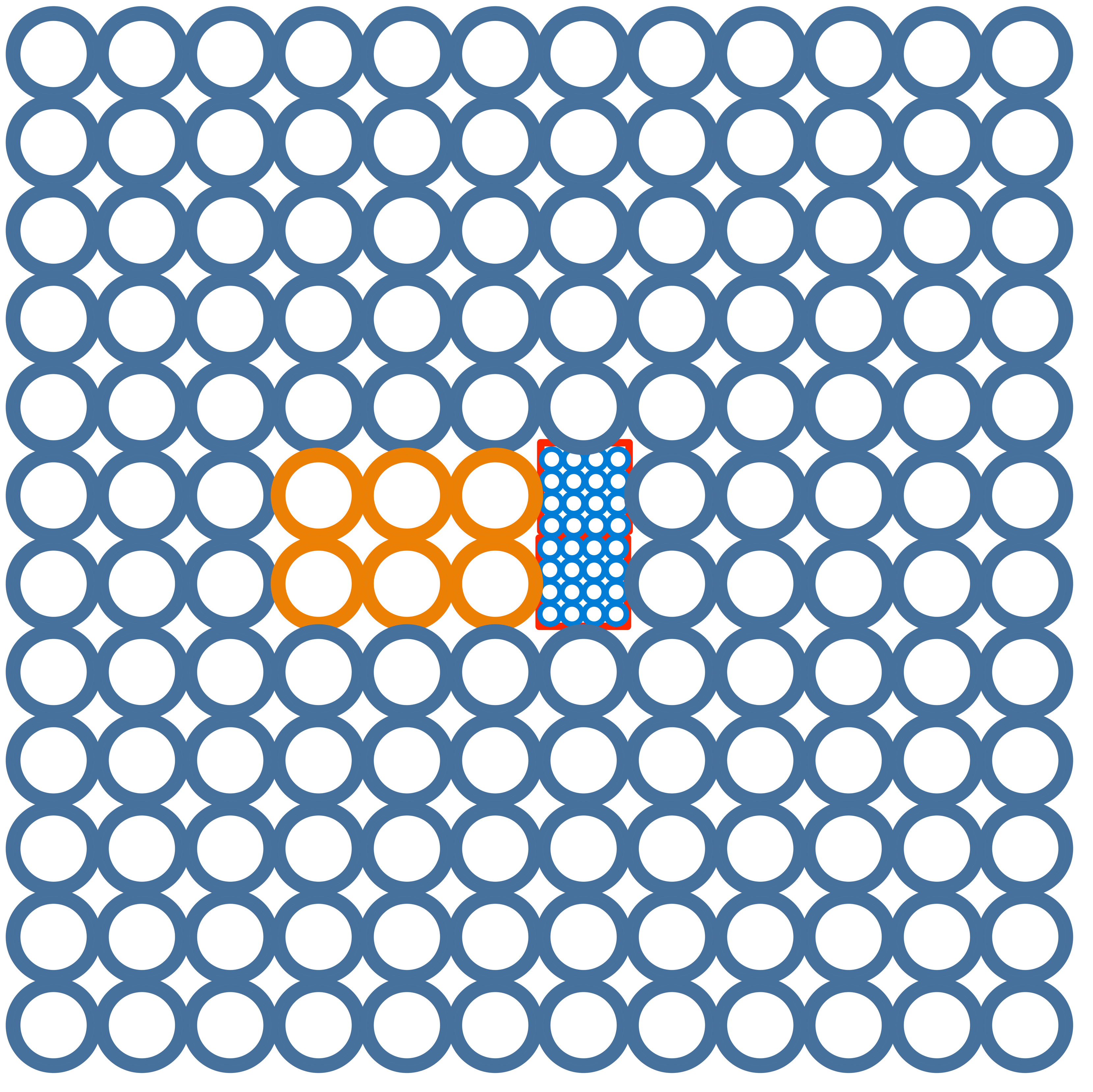
Focal plane image = 12x12 Fiber array – 800(ID)/880(OD)um ea.
Each Fiber core (800um) = 1km dia. GSD (iFOV)
=> 144 measurement channels



Focal plane central image = 4x4 fiber array (x4) 200(ID)/220(OD)um fibers = 250m sampling over 4km^2 (λ_1)

Delta Option

142+32=174
Total Channels



Systems Summary
Part II

Top-Level* Mass Summary Delta

(no contingency included)

Ocean Color Experiment 2	Mass CBE (kg)		% of Total Mass	
Scan Drum and Mechanism Assembly	46.8		13.9%	
Scan Drum Assembly		36.9		11%
Scan Drum Mechanism Assembly		2.1		0.6%
Half Angle Mirror Assembly		0.1		0.0%
Half Angle Mirror Drive System		2.6		0.8%
Momentum Compensation Assembly	26.9		8.0%	
Cradle Assembly	38.1		11.3%	
Cradle Structure		23.6		7.0%
Tilt Mechanism Assembly		2.1		0.6%
Calibration Target Assembly		4.9		1.5%
Aft Optics/Detector Assembly	99.3		26.6%	
Detector Array Assembly		61.4		18.3%
Digitizer Box	28.9		8.6%	
Main Electronics Box/ MEB	5.0		1.5%	
Mechanism Control Electronics Box/ MCEB	5.8		1.7%	
Harness	27.8		8.3%	
Thermal Subsystem	41.9		12.5%	
Pocketed Radiator Assembly		21.6		6.4%
5% misc Hardware	15.3		4.6%	
Total (+ 5% hardware and no margin):	**335.8**		**100.0%**	

*this listing does not include all subassemblies, please refer to the final mass model (MEL) for a full summary

Power Summary (Delta)

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OCE2 DELTA Configuration	Peak	Average
Scan Drum Assembly	**70**	**14.8**
Motor/Inductosyn	50	12
Half Angle Motor/Inductosyn	20	2.8
Launch Locks for Scan (powered by S/C)	4.5	0
Momentum Compensation Assembly	**50**	**47**
Cradle Assembly	**30**	**0**
Tilt Mechanism Motor 1/Resolver	15	15
Tilt Mechanism Motor 2/Resolver	15	15
Launch Locks for Tilt (powered by S/C)	4.5	0
Aft Optics Assembly	**458**	**442**
Preamp, FET switches, FET driver (1W each)	174	174
Digitizer Electronics Box (30W each)	110	110
Main Electronics Box	143	143
Mechanism Control Electronics Box	31	15
Operational Heater Power (described in Thermal & Electrical)	**99**	**69**
Instrument Total	**707W**	**573W**

Data Rates (Delta)

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<u>Instrument Detector Readout Data Rate</u>: instrument does not discard any data

- Assume 174 channels per scan
- 30 μs Integration Period
- Digitizing 16-bits, transmitting 14-bits each channel

⇒ **Raw digitized detector data: 81.2Mbps**

⇒ **2:1 compression implement in digitizer electronics (USES chip): 40.6Mbps**

<u>Additional Instrument Data that is included in the Instrument Data, but is negligible:</u>

- Housekeeping data (thermal, voltage, current, etc)
- Integration period measurements (taken for 12 detectors in both the baseline and delta instrument configurations)
- Dark current calibration images (possibly once per revolution)

<u>Instrument Packetization</u>: instrument data rate to the S/C

⇒ **There is 2% additional CCSDS overhead for packet headers: 41.4Mbps**

⇒ **Daily instrument data rate to S/C: 3577Gbits/day**

<u>Effective Instrument Downlink Data Rate from S/C</u>: the S/C may discard unuseful data for these considerations

⇒ **Discarding information beyond 102degrees**

⇒ **Discarding data beyond ±70 degrees latitude (over unlit Earth)**

Cost Assumptions (1 of 4)

Instrument Life Cycle

• Phase B Start	6/2014
• Instrument PDR	3/2015
• Instrument CDR	6/2016
• Start Integration	11/2016
• Payload Environment Review	8/2017
• Delivery to s/c or observatory	6/2018

Number of fully integrated flight units to build and cost

• Fully Integrated Flight Units	**1**
• Fully Integrated Flight Spare Units	**0**
• Fully Integrated Engineering Test Units (ETU)	**0**
• Fully Integrated Engineering Development Units (EDU)	**1**

Cost Assumptions (2 of 4)

Build Assumptions:

- Out of House (use non-proprietary contractor rates)

Cost Assumptions

- 2012 constant year dollars

Class of Mission

- Class B electronics

Throughput or Purchased Item(s)

- None at this time, although we are investigating actual cost of fiber optic harnesses as purchased, qualified, and integrated for LOLA and Atlas

Cost Assumptions (3 of 4)

- Detector costs will be estimated parametrically using SEER-H
  - We will also provide a grassroots estimate because the parametric option is for InGaAs and Silicon arrays vs. the single pixel detectors shown in this implementation
- Firmware development costs for FPGAs will be estimated using a grassroots scheme
  - This scheme assumes some firmware reuse based on Goddard spaceflight heritage
  - We assume that any other center or vendor providing this instrument would also have some firmware algorithms available for reuse
- FSW Software development costs are estimated parametrically using SEER-SEM
  - Again we assumed a certain amount of reuse and retest based on Goddard's heritage missions, and that any other center or vendor providing this instrument would also have algorithms available for reuse

Cost Assumptions (4 of 4)

The following costs are based on a percentage of the total instrument hardware costs

	Typical IDL Wrap	OCE2 Wrap
Ground Support Equipment (GSE) that is instrument-specific (that is, cannot be readily adapted from general purpose GSE)	5%	5%
Environmental testing at the Instrument Level	5%	5%
Component level flight spare components	10%	10%
Engineering Test Unit (ETU) @ Subassy Level	10%	10%
Instrument to S/C Integration and Test (typically included in WBS 10.0)	5%	5%
FSW GSE (this is taken from the FSW estimate, not the total instrument cost)	5%	Grassroots Scheme
Instrument FSW	5-10%, depending on the complexity and heritage	We are using SEER-SEM (but this should be evaluated against a 5-10% estimate as well)
Center Management & Overhead (CM&O),	Is specific to each NASA Center	N/A as an out-of-house build was assumed

OCE2 Mission Costing Approach

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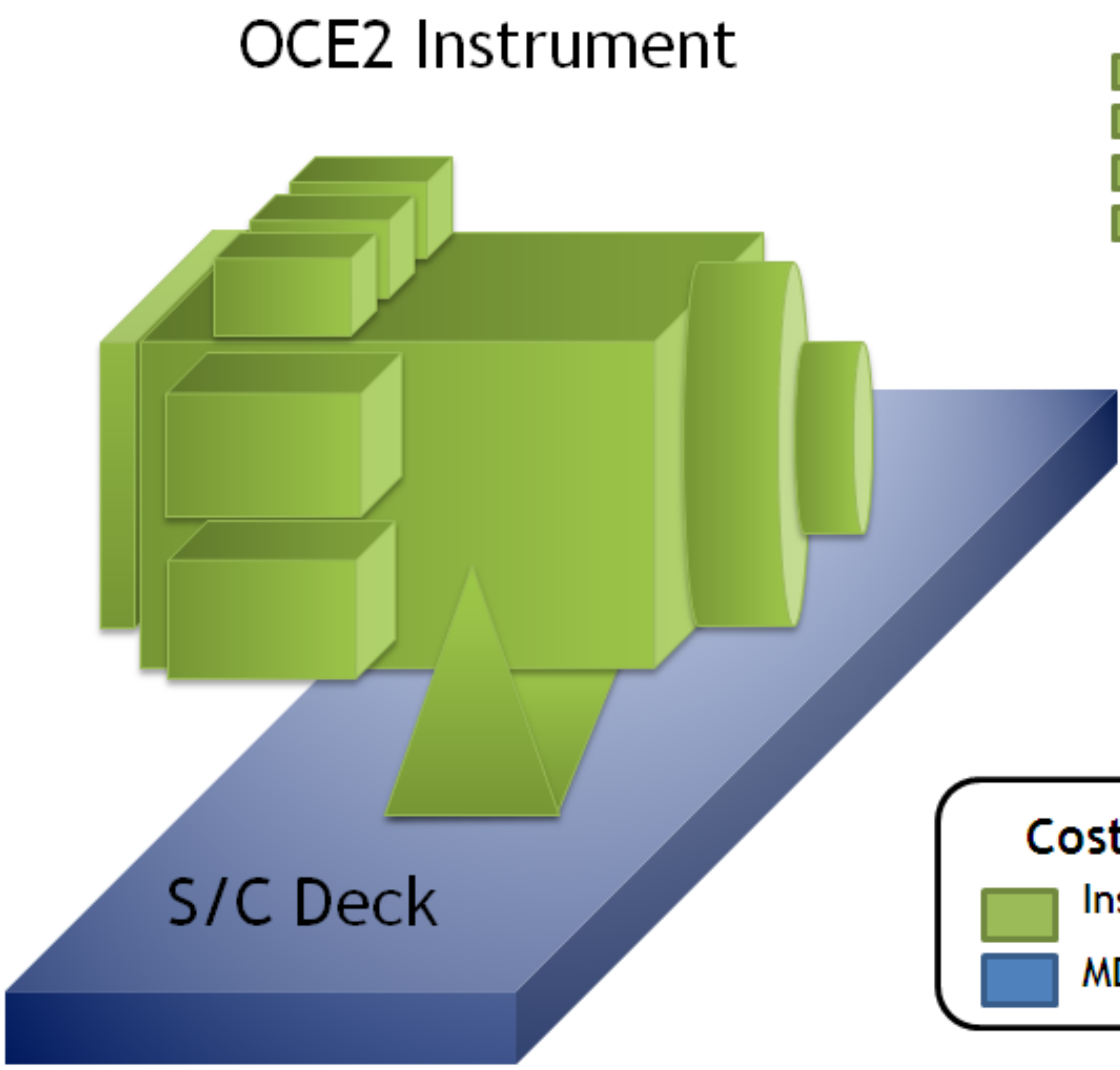

Additional Instrument Hardware

- Blankets
- Operational Heaters
- Survival Heaters
- Harness (all instrument harnesses terminate at the bulkhead on the side of the cradle)

Costing Key

- Instrument MEL
- MDL MEL

IDL Cost Products & Derivations

OCE2 Configuration	Redundancy Approach	Fore-optics Design	Radiator	IDL Products	Post-Study Cost Derivations
Primary study: 144 channels	Redundant mechanism control & knowledge	Singlet	Pocketed	Complete MEL + parametric cost product	
Delta study: 142+32 channels	Single string mechanism control	Doublet	Pocketed	Complete MEL + parametric cost product	
144 channels	Single string mechanism control	Doublet	Pocketed		Modular edit of cost estimates
142+32 channels	Redundant mechanism control & knowledge	Singlet	Pocketed		Modular edit of cost estimates

Conclusions

- **Larger number of detector channels leads to high power consumption for normal operations**
  - Will only grow with addition of more channels
  - Drives large radiators
- **Number of cycles on Scan Telescope, Half Angle Mirror and Momentum Compensation Mechanisms is very high**
  - 580 Million, 290 Million, and 2.33 Billion cycles respectively
  - Life testing will be a challenge
  - GSFC Gold Rule
    - 4.23 Life Test
    - Rule: A life test shall be conducted, within representative operational environments, to at least 2x expected life for all repetitive motion devices with a goal of completing 1x expected life by CDR.
- **Integration and Test of Optics/Detector and Assemblies Fiber Optics may be tricky**
  - Fibers must remain stable to preserve throughput characteristics
  - Potential accessibility issues if there are failures after integration
  - Singlet lenses will require a shim inserted into the assembly - the shim would be a specific dimension for each detector in the 144 channel set

Recommended Future Work

- **Continued evaluation of fiber optic layout**
  - Include results of testing of flight fiber optics materials
- **Characterize fiber optic attenuation over wavelengths**
- **Search for lowest power part options for detector readout and digitization electronics**
  - Small reduction can yield large saving given the large number of repeated components
- **Define requirements for processing of direct broadcast data**
- **Refine requirements for regions of valid science data acquisition**
  - More accurately define data volume
- **Reevaluate implementation of Momentum Compensation Mechanism**
  - Incorporate into Half Angle Mirror Mechanism?
  - Reduce number of cycles of Momentum Compensation Mechanism (larger wheel)
  - SeaWifs design incorporated a lubricant reservoir to extend the lifetimes of the spinning mechanism
- **Evaluate having S/C perform +/-20 deg tilt and eliminate tilt mechanism**
- **Re-optimize Optics for 700 km altitude**
- **Optimize depolarizer geometry**
- **Consider alternate design for Half Angle Mirror**
- **Investigate best approach for use of AR coatings**
- **Investigate radiator configurations (flat vs pocketed)**
- **Investigate contamination sensitivity and the possible need for a 1-time use aperture cover**